Artificial Gravity for Protection of Human Health during Long-Duration Spaceflight

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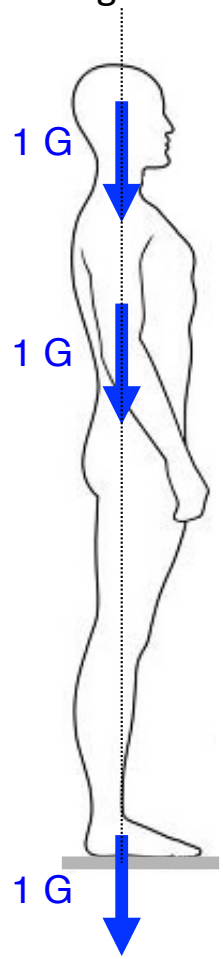
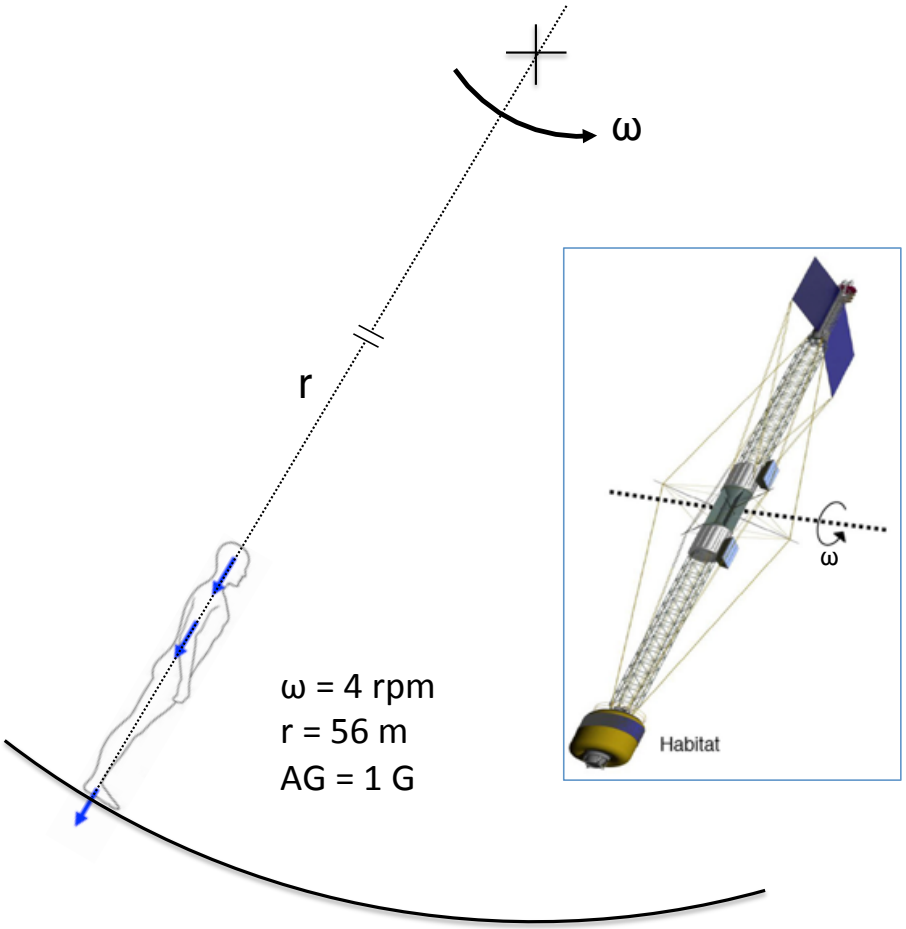
Why Use Artificial Gravity?

- NASA's vision for space exploration include scenarios that would send humans beyond LEO for long duration periods.
- Artificial gravity (AG), by reproducing the normal 1G environment, has the unique feature of protecting all physiological systems in all individuals against the effects of weightlessness.
- The selection of the final health protecting countermeasure suites should include consideration for AG, not just traditional methods.
- AG is feasible from an engineering aspect, but more research is required to define the fundamental operating parameters for an AG countermeasure.

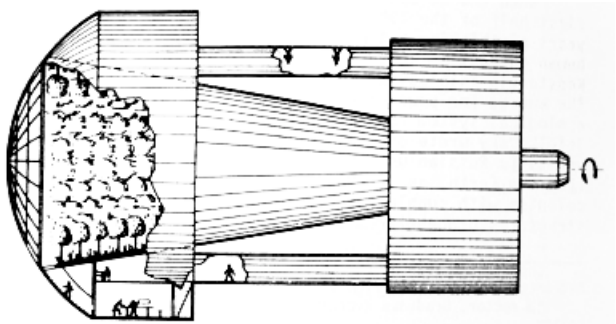
Standing on Earth



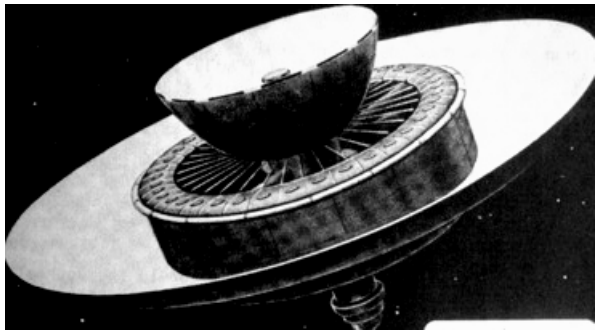
Standing in a Rotating Spacecraft



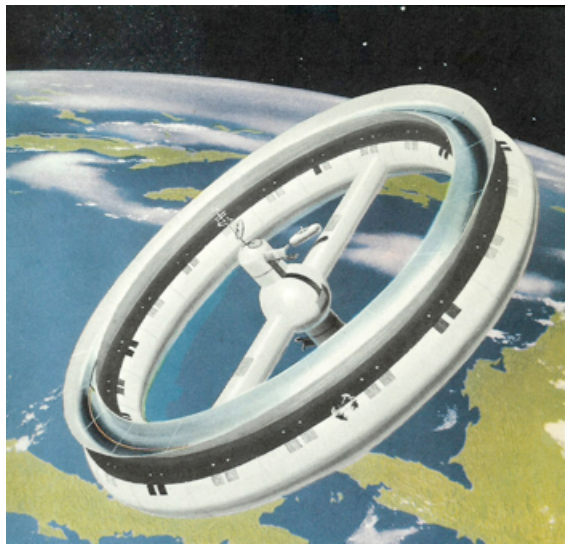
Historical Concepts



Tsiolkovsky (1903)



Noordung (1928)



Von Braun (1952)

NASA LaRC (1962)

Human Risks of Spaceflight

Grouped by Hazards – 30 Risks & *2 Concerns*

Altered Gravity Level

- Vision alterations
- Renal stone formation
- Sensorimotor alterations
- Bone fracture
- Impaired performance
- Reduced aerobic capacity
- Adverse health effects
- Urinary retention
- Orthostatic intolerance
- Back pain
- Cardiac rhythm problems
- *Effects of medication*
- *Intervertebral disk damage*

Radiation

- Exposure to space radiation

Distance from Earth

- Limited in-flight medical capabilities
- Toxic medications

Isolation

- Adverse cognitive or behavioral conditions
- Performance & behavioral health decrements

Hostile/Closed Environment–Spacecraft Design

- CO2 exposure
- Inadequate food/nutrition
- Inadequate human-system interaction design
- Injury from dynamic loads
- Injury during EVA
- Celestial dust exposure
- Altered immune response
- Hypobaric hypoxia
- Sleep loss & work overload
- Decompression sickness
- Toxic exposure
- Hearing loss
- Sunlight exposure

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Risks potentially minimized by artificial gravity

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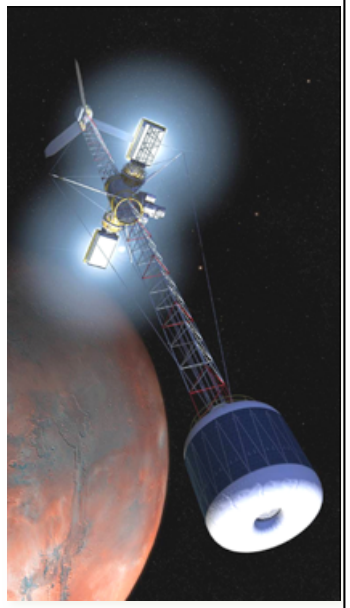
Artificial Gravity (AG) Potential Benefits

- Current countermeasures address the debilitating effects of microgravity in a piece-meal fashion. Artificial gravity produces multi-system effects.
- Better to prevent issues rather than to apply countermeasures after the fact.
- AG reduces countermeasure requirements during transit and on planetary surface.
- Affects timing of crew transfer to surface habitat, lander sizing.
- Rehabilitation starts 6 months earlier than a non-AG mission, and is complete when crew returns to Earth.
- Lower development costs for items used only at 1G.



Sullivan T (2014)

Vehicle Designers Concerns & Perception

- Lack of definitive design requirements, especially acceptable artificial gravity levels and rotation rates.
- Perception of high vehicle mass and performance penalties.
- Incompatibility of resulting vehicle configurations with space propulsion options.
- Perception of complications associated with de-spun components such as antennae and photovoltaic arrays.
- Expectation of effective crew microgravity countermeasures.

Kamman et al. (2004)

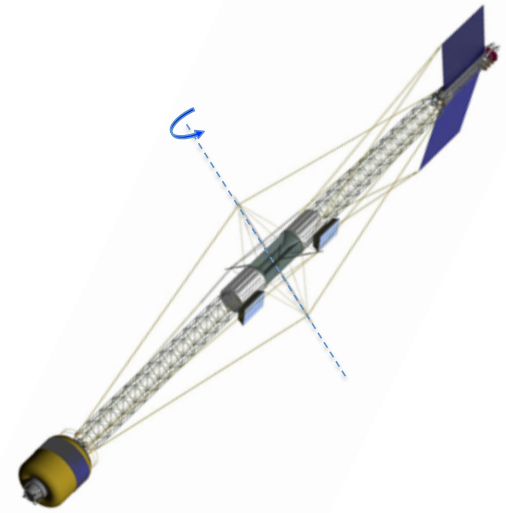
Products Necessary to Resolve Open Questions

- The evidence base necessary to advise engineering designers on optimal radii, rotation rates, angular accelerations, centrifugal force, etc. to be used in designing rotating vehicles.
- The evidence base necessary to devise optimal prescriptions for application of short-radius, intermittent AG, with and without augmentation by exercise or other countermeasures.
- The biomedical database necessary to fully characterize the multisystem physiological consequences of long-term exposure to hypogravity environments expected during exploration class missions (0.16G, 0.38G, and possibly other G-levels).
- The biomedical database necessary to fully characterize short and long-term, multisystem responses to transitions between gravity levels.

Kamman et al. (2004)

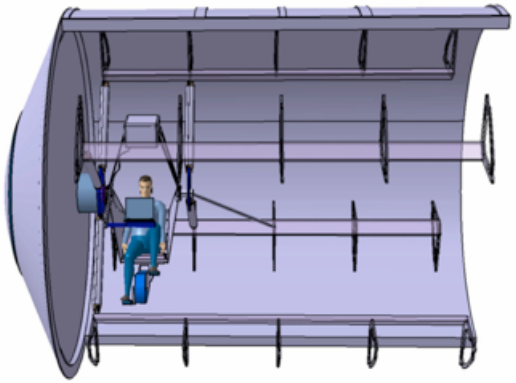
NASA AG Project

- **Goal**
  - Determine the design trade space associated with AG for Mars missions vehicles and habitats.
- **Objectives**
  - Implement an evidence-based, peer-reviewed, coordinated R&D project to investigate AG.
  - Determine the optimal design characteristics for a AG countermeasure.
- **Milestone**
  - Decision criteria whether AG can protect crew health and performance during human deep space missions expected NET 2022.



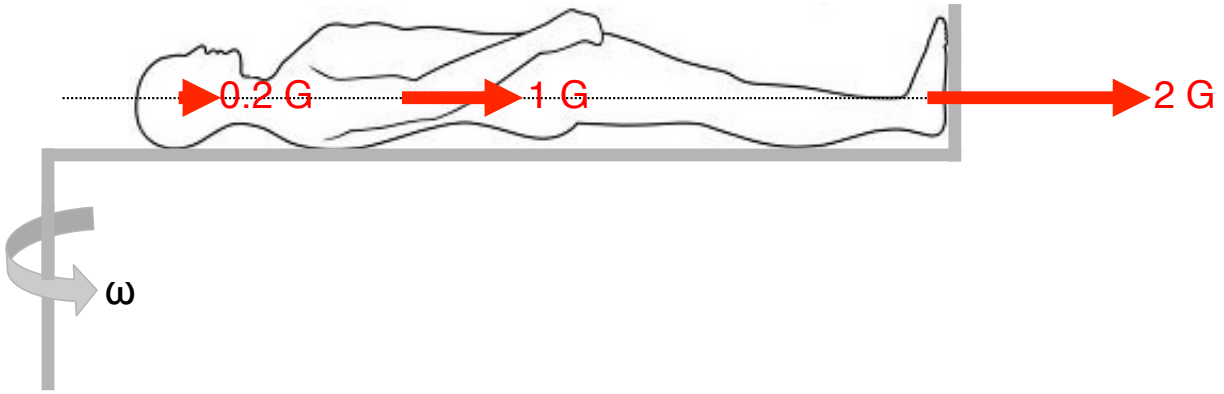
Rotation of the whole vehicle
e.g. Mars NTR
r = 56 m
ω = 4 rpm

Rotation of part of the vehicle
e.g. Nautilus-X
r = 6 m
ω = 12 rpm

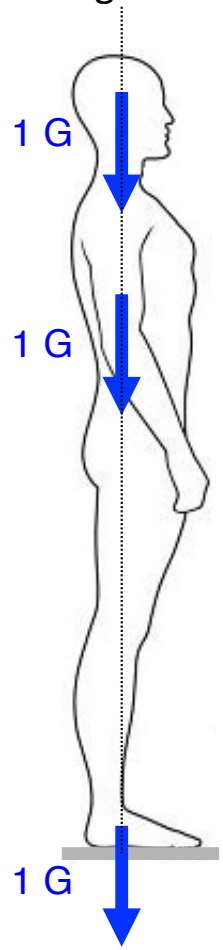


On-board centrifuge
e.g. AGREE
r = 1.6 m
ω = 24 rpm

Short-Radius Centrifugation in Space



Standing on Earth



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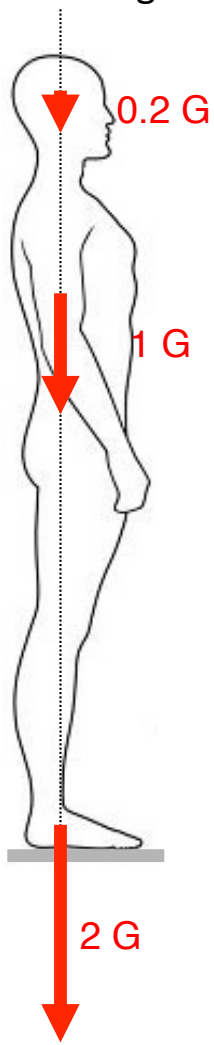
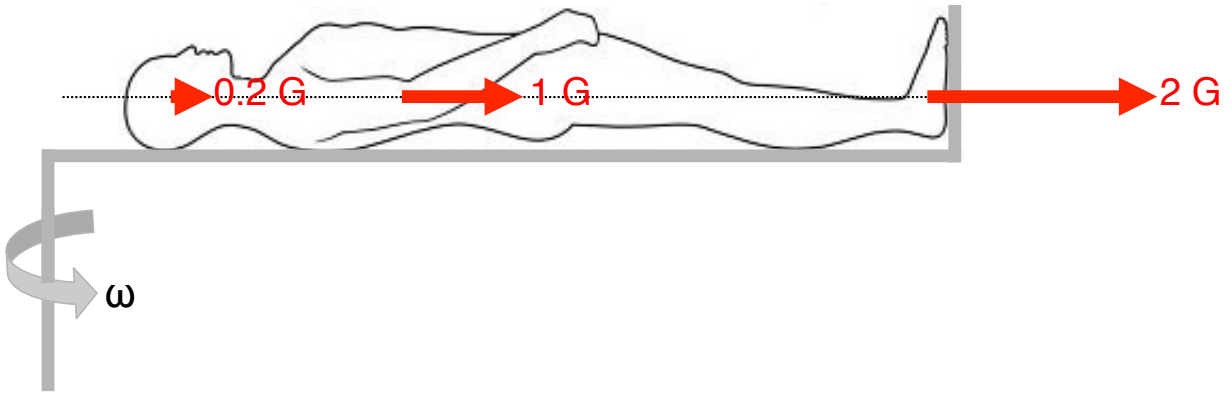
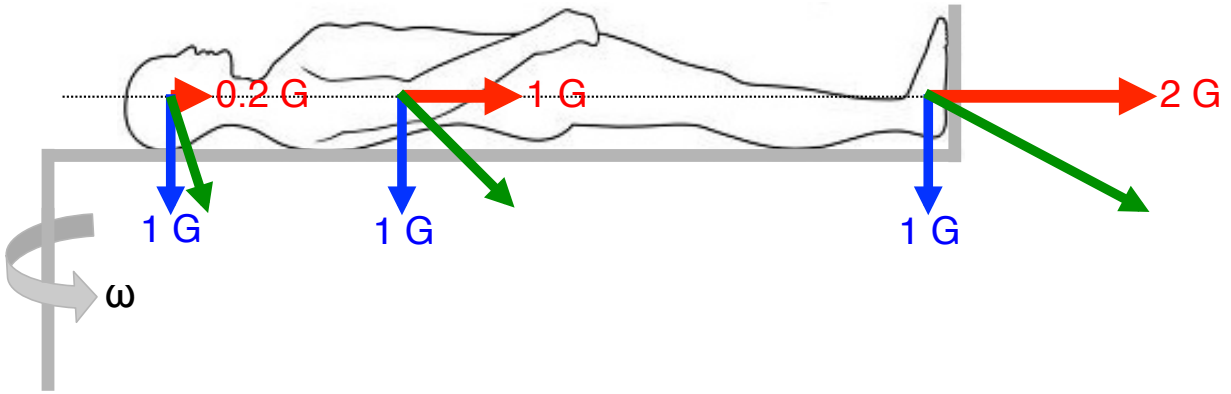


Short-Radius Centrifugation in Space

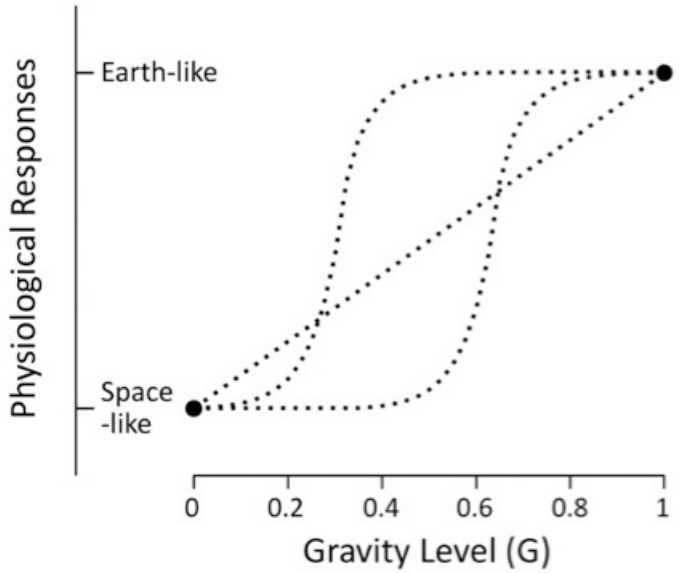


Short-Radius Centrifugation on Earth



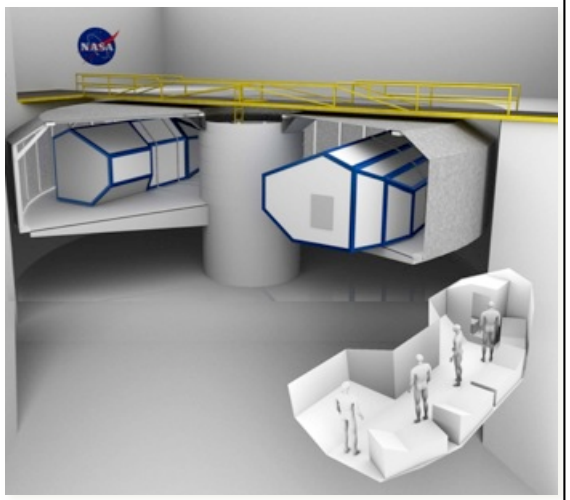
AG Research Plan

1. **AG Level**
   - G dose-physiological response relationship
   - Humans, rats, cells
   - Ground-based studies:
     - Bioreactor
     - Random Positioning Machine
     - Body Unloading
     - Centrifugation
     - Parabolic flight
     - Computational Models



AG Research Plan (cont'd)

2. **AG Duration**
   - Continuous rotation
     - Large-radius centrifuge / habitat
   - Intermittent rotation
     - Short-radius centrifugation during bed rest / dry immersion



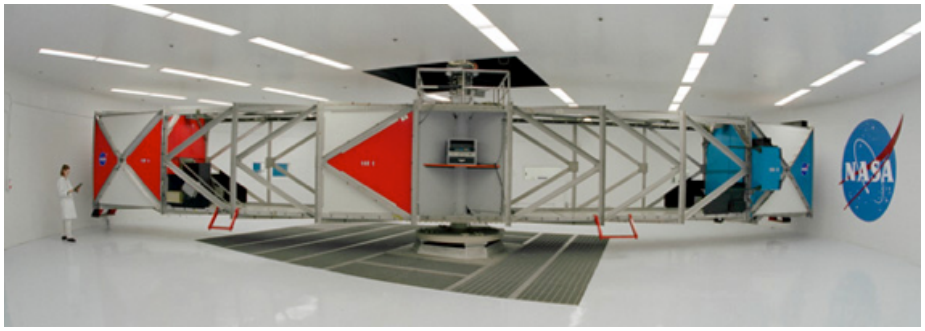
NASA ARC Rotating Habitat

Wyle IMAG short-radius centrifuge

AG Research Plan (cont'd)

3. **Health Consequences of AG**
   - Cross-coupled & Coriolis accelerations
     - Rotating chair
     - Slow Rotation Room
   - Gravity gradient
     - Large-radius centrifuge
   - Intracranial pressure
     - Large-radius centrifuge

Brandeis University slow rotating room

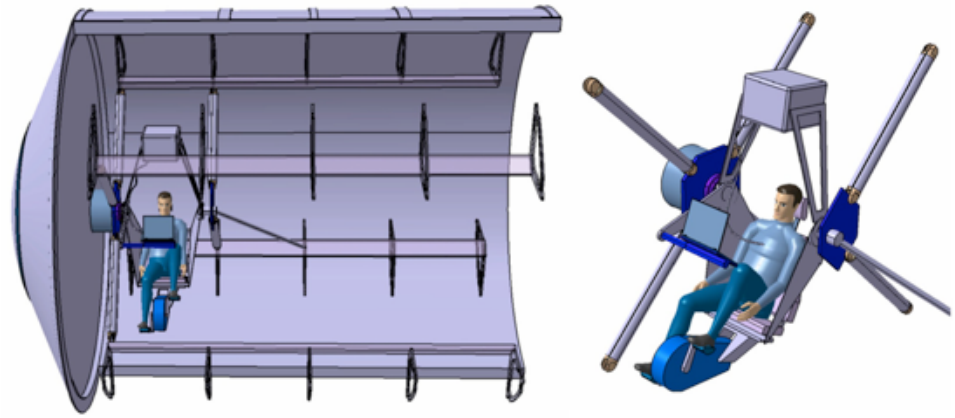


NASA ARC centrifuge

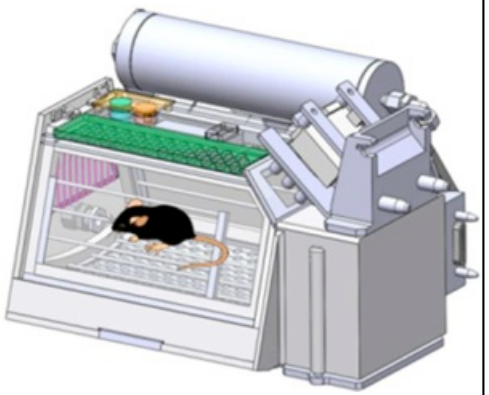
AG Research Plan (cont'd)

4. **Validation of AG Prescription**
   - Comparison between animal centrifugation on the ground and in space
   - Space operations of a human short-radius centrifuge
   - Human centrifuge in space

Cosmos-936 rat centrifuge



AGREE ISS human centrifuge



JAXA ISS mice centrifuge

AG Project Status

- **March 2014** – HRP approval to initiate the Artificial Gravity project to develop evidence-based recommendations for or against the use of AG in deep space transit vehicles by 2022.
- **September 2014** – Creation of Intern'l AG Working Group as a sub-group of the International Countermeasure Group.
- **December 2014** – External AG Advisory Panel.
- **March 2015** – Evidence Report on Artificial Gravity. Available at: http://www.xxx.xxx
- **May 2015** – Research Plan, in progress.
- **June 2015** – Project Management Plan, in review.
- **July 2015** – Research solicitation.

Research Solicitation

- **Website: NSPIRES?**
- **Deadline: ?**
- **Programmatic considerations**
  - The PIs of the selected proposals will join a NASA-led *translation and integrative research coordination team* for optimizing outcomes of research and data sharing.
- **Multinational research participation**
  - ISS international partners are strongly encouraged to participate as co-investigators.